4-05-65-5 • DECEMBER 1965

4-05-65-5

FINAL SUMMARY REPORT

STUDY OF SPACECRAFT ON-BOARD TEST AND DATA PROCESSING TECHNIQUES

Lockheed

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FOREWORD

The work described in this report was performed by Lockheed Missiles & Space Company for the Ames Research Center, National Aeronautics and Space Administration, under Contract NAS 2-2479. This document, the Final Summary Report, represents the third of three reports submitted for this study. Contained herein is a summary of the work on the "Study of Spacecraft On-Board Test and Data Processing Techniques" carried out from 13 October 1965 through 7 June 1965 under the direction of Ames Research Center, Moffett Field, California.

The other two documents resulting from this study are:

- Final Report (LMSC Report No. 4-05-65-3)
- State-of-the-Art Biological Data Handbook (LMSC Report No. 4-05-65-4)

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Section 1
INTRODUCTION

The objectives of the study described in this report were to determine the state-of-the-art in biological instrumentation and on-board data processing for biological space missions, to project requirements for future missions, and to postulate data system configurations for these missions. Throughout the study, emphasis was placed on the assessment of data loads imposed on the telemetry system by information sources in these missions. The study was divided into three phases: a survey, a comparative analysis, and a system projection for future missions.

The detailed report on this study is contained in the final report "Study of Spacecraft On-Board Test and Data Processing Techniques," LMSC 4-05-65-3. This companion document is a summary of the final report and does not contain specific data; rather, an overall synopsis of the study program is given. In addition to this report and the final report mentioned above, a third document has been submitted as part of the study contract requirements, that is, "State-of-the-Art Biological Data Handbook," LMSC 4-05-65-4.

Section 2
SURVEY

As indicated in the introduction to this report, the major objective of this study program was to project on-board data system requirements for future biological space missions. As part of this projection, deficient areas were to be isolated and reported to ensure that design efforts can be undertaken in subsequent efforts to remove these deficiencies, or that sufficient other capability is provided, at additional expense, to obviate the need for the deficient capability. A prerequisite to completing such a projection satisfactorily is adequate knowledge of the current state-of-the-art.

With these overall objectives in mind, a survey of current capabilities for on-board biological data systems was conducted. This survey effort consisted of two independent, concurrent efforts. First, in one investigation, emphasis was placed on tests, measurements, and signal-conditioning equipment. The other investigation concentrated on data systems associated with on-board biological experimentation. Each survey investigator remained cognizant of the work in his counterpart's area and gathered pertinent data where possible, although the task of organizing, sifting, and analyzing the acquired data remained the specific responsibility of only one investigator in each survey area. This parallel approach proved effective in both data acquisition and elimination of redundant data listings.

The main purpose of the survey was to acquire sufficient knowledge concerning the state-of-the-art techniques in biological and biomedical areas and equipment so that a realistic comparative analysis as well as a meaningful projection for future on-board system requirements could be made. Therefore, prior to initiation of the survey, to assure that pertinent data were obtained in as uniform a manner as possible, data acquisition sheets were introduced. These sheets, one type for transducers and sensors and another for systems, consist of a number of generic headings with a column in which to enter pertinent data for the subject equipment. In addition to providing a unified manner for listing gathered data, these sheets resulted in a concise specification listing that was beneficial during the comparative analysis phase that followed the survey. Further, during meetings and telephone calls with experimenters and other people concerned with biological instrumentation, these sheets served as a guide to ensuring that all pertinent and available data had been obtained. The initial generic headings were modified during the survey to more adequately represent actual specifications found to be most universally reported. The ultimate formats of these two standardized forms are used in both the final report and the handbook submitted at the conclusion of the study to present the data gathered on the various flight-qualified equipments. An example of a transducers and sensors data accumulation sheet is shown on p. 2-3.

2.1 METHOD OF SURVEY

The main effort of the survey was concentrated primarily in a literature search, although experimenters and bioinstrumentation manufacturers were also consulted either by telephone or wire. The literature search was conducted by information retrieval specialists at LMSC's Technical Information Center (TIC) under the direction of the study leader. The following sources were searched:

	SOURCE	PERIOD
(a)	International Aerospace Abstracts	1961 through 1964
(b)	NASA Star	
	(1) Unclassified	1962 through No. 21 of 1964
	(2) Classified	1963 through No. 18 of 1964
(c)	DDC (ASTIA) TABS	1963 through No. 22 of 1964
(d)	DDC Computer Reference Retrieval	1960 through 1964
(e)	International Biological Abstracts of Biological Sciences*	Note 1*
(f)	Biological Abstracts*	Note 1*
(g)	LMSC Card Catalog and Holdings	1960 through 1964

*Note 1: Sources (e) and (f) were given brief attention since all references found were also located in either or both sources (a) and (b).

TRANSDUCERS AND SENSORS DATA ACCUMULATION SHEET

MEASURAND	Pressure
MODEL, SERIES	Type 4-312 Medium Range Unit and Low Range Unit
MANUFACTURER	Consolidated Electrodynamics, Transducer Division
OPERATING PRINCIPLE	Unbonded strain-gage windings connected in a four-arm bridge used as sensing element for this variable-resistance-type transducer.
MEASURAND RANGE	0 to 26 psi through 0 to 150 psi gage, absolute, and unidirectional differential types ± 16 through ± 5.0 psi bidirectional. Standard ranges: 0 to 50, 100, and 150 psi gage, absolute, and unidirectional differentials, ± 25 and ± 50 bidirectional differential.
LOW RANGE UNIT	All specifications similar to above except the following: Pressure range: 0 to 10 psi through 0 to 25 psi gage, absolute, and unidirectional differential, and 5 psi through 15 psi bidirectional differential Standard ranges: 0 to 10, 15, 25 ps, gage, absolute, and unidirectional differential, and 5, 7.5, 12.5 psi bidirectional differential Natural frequency: 3,000 cps for 10 psi (5 psid) transducers increasing logarithmically with pressure range to 8,000 cps for 25 psi (± 15 psid) transducers
SENSITIVITY	At rated excitation, open circuit, +77°F-gage, absolute, and unidirectional transducers: 20 mv +30%, -10%, birdirectional ± 10 mv + 30%, -10%
OVERRANGE FACTOR	1.5 times rated pressure when applied for 3 min, does not cause a zero set to exceed 1% full-range output
LIFE EXPECTANCY	
TIME CONSTANT AND/OR FREQUENCY RESPONSE	Natural Frequency: 8,000 cps for 26-psi transducers, increasing logarithmically with pressure range to 17,000 cps for 150 psi transducers.
ENVIRONMENTAL RANGES AND EFFECTS	Compensated temperature range: -65°F to +250°F; Operable Temperature Range: -320°F to +300°F; Thermal zero shift: within 0.012% FR/°F over compensated temperature range. Thermal sensitivity shift: within 0.01% FR/°F-7.
ACCURACY	Residual unbalance: within ± 10% of full-range output at zero pressure, rated excitation, +77°F
RESOLUTION	Linearity and hysteresis combined effects as measured from the best straight line through the calibration points do not exceed: ± 0.5% FR – gage, absolute, and undirectional differential; ± 1.0% FR – bidirectional differential transducer.
LINEARITY	
OUTPUT IMPEDANCE	350 ohms ± 5% at 77°F
HYSTERESIS	
METROLOGICAL PARAMETERS	5 VDC or 5 VAC, rms; carrier frequency 0 to 20 kc maximum
a. Excitation	10 VDC or 10 VAC rms without damage
b. Input Impedance	350 ohms ± 5% at 77°F, 1/2-in.-diam., 3/4 in. long
c. Gage and Absolute	10 gms maximum; differential: 13 gms maximum; flange, gasket, and screws: 9 gms maximum
FLIGHT QUALIFICATIONS	Flyable
REMARKS	
RANGE	Maximum internal pressure: 75 psig
REFERENCE	9
CLASS	Pressure
RANK	1

This literature search yielded more than 500 documents that appeared to fit the descriptors governing the search.

In addition to the documents made available from the literature search, a number of brochures and specification sheets were obtained from manufacturers of biological and biomedical equipment. The names of these manufacturers were obtained from three sources:

(a) References in documents obtained during the literature search
(b) Listings of biomedical manufacturers in Electronic Buyers Guides
(c) Discussions with manufacturers' representatives

More than 100 companies were contacted.

A third source of information was the files of the Bioastronautics organization of LMSC. These files contain information on a number of systems, sensors, and signal conditioners. A listing of such equipment as needed in the subject study was made by LMSC personnel during a concurrent study, and much of these data were applicable after some modification in listing format.

2.2 RESULTS OF SURVEY

Throughout the survey, it became increasingly evident that data problems for biological missions (biological here is contrasted to biomedical) do not present any serious difficulties for current missions, or are such difficulties anticipated for future missions. This stems from the fact that for biological missions as such, few measures are required.

Possible exceptions are data requirements that may arise in biological missions for television coverage. This requirement, however, is also found in biomedical missions, and comments applicable to such missions would be equally applicable to biological missions. This is equally true for the general conclusion; that is, many requirements recognizable as being important for biomedical missions are also applicable to space missions in general. Accordingly, effort expended throughout the remainder of the study was concentrated on biomedical aspects and associated data problems.

A previous report on survey results has been submitted to the contracting office under the title, "Results of the State-of-the-Art Survey of Spacecraft On-Board Biological Systems." The contents of that report are included in the final report except for data obtained during the survey on non-flight-qualified equipment. The data on flight-qualified items are presented in the final report on the data accumulation sheets that were previously described. In addition to the listing of specifications for an equipment item, a cross-listing of references from which the data were obtained is provided for future recourse to the equipment originator to obtain more information if desired. The report on the survey is concluded with a complete listing of all references obtained during the survey, as well as a listing of the names of all manufacturers contacted as part of this study phase.

Section 3
COMPARATIVE ANALYSIS

The ultimate objective of tests, measurements, and associated data systems is the presentation to the experimenter of results of the tests, measured magnitudes, and a time history of the process being investigated. The judgment of the merits of a system, therefore, must be based on the efficacy with which these objectives are achieved. During the survey period a number of system components for on-board biological and biomedical data systems were described in terms of available specifications. Any future system will make use of either these components or their successors. These successor configurations will be either the normal evolutionary improvements encountered in all equipment areas, or they will be basically different configurations devised to overcome deficiencies in existing designs. Other component designs must be developed for future systems in areas where, to date, no flight-qualifiable equipment has been available.

To adequately fulfill the major objective of this study, it is imperative that an objective judgment be made concerning the relative merits of equipment known to be available. To be able to make the required judgments objectively, some "standard" or "yardstick" must be available for use in this evaluation. Also, to postulate future systems, information relative to anticipated requirements and measurements must be available to properly assess the capability of current components in fulfilling these requirements and performing the measurements. Therefore, during the comparative analysis phase of this study, the following tasks were undertaken:

- Definition of characteristics of measurable phenomena and establishment of a "standard" for each measure
- Investigation of anticipated measurements and processes for future missions
- Comparison of available specifications of currently available equipment with the standard and establishment of an objective ranking
- Analysis of redundancy-reduction techniques elicited during the survey

3.1 DEFINITION OF CHARACTERISTICS OF MEASURABLE PHENOMENA

A review of the literature elicited during the survey discussed in the previous section failed to reveal the standards necessary for an objective evaluation of the equipments. The first task in the comparative analysis therefore was for the study team to establish the required standards. Writing specifications for all possible on-board biological and biomedical functions and measures would be a monumental task, especially in light of the large number of measures postulated for such missions. To establish standards for all such measures would require more time than could be justifiably expended during the study and would possibly even exceed the study guidelines. For this reason a restriction was imposed on this effort to consider only those parameters for which specific equipment specifications had been elicited during the survey, thereby providing sufficient data to complete the comparative analysis. The fact that this limitation was imposed is not meant to minimize the importance of having such standards for all measures; in fact, it is a recommendation of the study team that such an effort be included in, or be the sole subject of, a future study.

Each of the measurement areas for which equipment was found during the study was thoroughly evaluated to determine the important characteristics. Using the available literature and the cumulative experience of the study team members and LMSC space medicine experts, as well as other sources where applicable, standards were established for the following measurements:

(1) Electrocardiogram, ECG
(2) Electroencephalogram, EEG
(3) Electromyogram, EMG
(4) Galvanic/Basal Skin Response, GSR/BSR
(5) Electroocculogram, EOG
(6) Blood Pressure
(7) Pulse Rate
(8) Body Temperature (Skin and Core)
(9) Respiration (Rate and Depth)

(10) Seismocardiogram
(11) Respiratory CO_2 and O_2
(12) O_2 Dissolved in Blood
(13) Dosimetry

3.2 ANTICIPATED MEASUREMENTS FOR FUTURE MISSIONS

Data systems for future missions will vary in accord with the number and type of measures that will be made. The previous subsection was devoted to a discussion of an effort which provided specifications for measures that can currently be made. To obtain sufficient information to predicate future systems, this current capability must be compared with the anticipated requirements for these future systems. As in the previous cases described in this report, the starting point for this determination of anticipated measurements was the literature found during the survey phase. In addition, some information was available from current studies being conducted to assess and configure future biological and biomedical missions such as BIOS, BIOLABS, and MOL. This effort reinforced the conclusion reached as a direct consequence of the survey; that is, biological missions do not present a major problem in the area of data systems except for the television coverage that may be required in some cases. The real problems will be encountered in biomedical flights.

As a result of the effort to determine anticipated future measurements, a list was generated that contained (of all those measures found) those which appeared most important and most probable to the study team. In all, some 115 different measurements, or parameters derivable from basic measures, are tabulated. This tabulation appears in both the final report and the handbook.

3.3 COMPARISON OF EQUIPMENT AGAINST STANDARDS

Once standards had been established for all equipment elicited during the survey, a comparison of each equipment specification with its counterpart in the standard proved a simple task. Within each class of measure, a relative ranking was made. The component with specifications most closely approximating the standard was ranked number one and the remainder ranked in numerical sequence of lower order in a similar manner. This relative ranking number has been included on each data accumulation sheet presented in the final report and the handbook.

3.4 ANALYSIS OF REDUNDANCY-REDUCTION METHODS FOUND DURING THE SURVEY

Two methods postulated for data-compression techniques were found during the survey. The methods were generated specifically for use with biomedical data. As part of the comparative analysis phase – but more importantly from the standpoint of data loading being of major concern during this study – attempts were made to analyze the operation of each of these data-compression formats.

The first method consists of an eight-channel PPM/FM telemetry system utilizing two reference pulses instead of one. The time between these two pulses could be chosen to be any one of eight times. Detail available on this system was not sufficient to permit a complete analysis of the operation and subsequent determination of how bandwidth reduction was achieved. However, it was observed that this accomplishment had to be connected with the ability to encode information as a function of the eight selectable periods between reference pulses.

The second of these systems comprises a series of quite complex operations involving thresholding, rectification, and determination of zero crossings, among others. In addition to the selection of these complex operations, it appeared that some purely arbitrary operations were performed, such as selection of the sampling rate without regard to the frequency response required by the parameter being compressed. After a thorough analysis of this technique, it was determined that the process is equivalent to the summed output of three low-pass filters, each with an attenuator and a delta function at DC. The delta function is really of no import and results only from the fact that the process is of non-zero mean. If the operations involved in this method prove to be really desirable, the filters and attenuators might be a more logical and simple way of implementing the process. The relationships between the degree of attenuation, filter corner frequency, and the threshold values can be interpreted directly from the analysis presented in the final report. This method provides a means of bandwidth reduction through the operation of low-passing the data. In addition, arbitrary selection of a sampling rate will also provide a means of reducing the output sample rate, but this at the expense of incurring considerable aliasing error.

Section 4
DATA COMPRESSION

This section is devoted to a specific problem encountered in many current data systems and one that must be solved to satisfy demands of future data systems. This problem is management of the large volumes of data obtained during space mission operations – i.e., establishing means of compressing the data to save bandwidth, power, processing, and storage requirements, or a combination of these. Presentation of this material before consideration of the data system may seem somewhat premature. However, data-compression techniques in data systems show an ever-increasing importance, and since findings in this area will make it easier to understand the reasoning used in the data system configuration described in subsequent sections, data compression is discussed here.

4.1 DESCRIPTION OF DATA COMPRESSION MODES

Any discussion of data compression must be preceded by an understanding of what is being attempted. Throughout this report, data compression is defined as that process whereby useful and meaningful information is extracted from the time series generated by some data source, with the remaining data considered redundant and discarded. This definition does not specify the nature of the information. Information is an ambiguous term and is interpreted differently under varying conditions. For any given segment of a data time-series ensemble, three different levels of information can be identified. These levels are discussed in depth in the final report; nevertheless, a very brief description will be presented here.

Three levels of information arise directly from recognition of three levels of data compression. These various levels of compression were observed to be necessary during evaluation of mission operations for future biomedical space flights. The three levels of compression have been termed Syntactic, Pragmatic, and Semantic. "Syntactic" refers to variations in information content with choice of code symbols, the total number of symbols from which any one may be chosen, and the ordering of these symbols and groups of symbols. "Pragmatic" refers to the ultimate use of the information; that is, if some ultimate action is initiated by the information it has been pragmatically useful; whereas, if it is observed and discarded, it is not information in the pragmatic sense. As in any language, some messages have a greater semantic content or contain more semantic information than others for a given source condition.

In light of these definitions of the various types of information and the definition given at the beginning of this section for a data compressor, the conceptual functions of the Syntactic data compressor, the Pragmatic data compressor, and the Semantic data compressor are readily seen. The Syntactic data-compression mode encompasses the entirety of currently available algorithms for the removal of redundant data from a data series. The type of information retained by these algorithms is essentially that treated by the subject of Information Theory. A detailed discussion of the functional operation of any of the data-compressor modes exceeds the scope of this summary report; therefore, for further description the reader is referred to the study program final report.

During the study, effort expended on Pragmatic and Semantic data compression (after initial recognition of the future necessity for these techniques) was restricted to definition and classification of the compression modes discussed above, and to the establishment of the basic philosophy concerning the conceptual configuration and application of such systems. A greater effort was expended on Syntactic data compression since algorithms are currently available that operate in this mode.

4.2 SYNTACTIC DATA COMPRESSION

A major concern at the beginning of the study (and specifically mentioned in the Request for Proposal that initiated the contract procurement) was the data loading of the telemetry systems in biological and biomedical missions. The actual loading to be anticipated was determined as part of this study and is discussed in Section 5. Concurrent with the effort of assessing data loading, an investigation was undertaken to determine the effectiveness of the currently available algorithms on biomedical data.

An essential part of current and future manned missions is the pictorial coverage provided by an on-board television system. Although not truly a biomedical measure, television can provide a tremendous amount of data to trained medical personnel. A number of studies whose main objective was the evaluation of video compression were conducted by LMSC concurrently with the study described here. Since the results of these studies were available for inclusion in the data handbook, no further effort was undertaken to evaluate video compression as part of the present work.

The investigation of Syntactic data compression as applied to biomedical data was divided into two parts:

(1) Evaluation of the effectiveness of currently available Syntactic data-compression algorithms on biomedical data
(2) Analysis of Syntactic data compression

4.2.1 Effectiveness of Compression Algorithms on Biomedical Data

Data compression has generally been applied to what may be termed normal telemetry data (to distinguish them from biomedical data). Such data include pressures, temperatures, positions, voltage levels, and other physical quantities. All of these functions share one common characteristic – a basically statistical structure of the time series in question. Biomedical data, by the very nature of their generation, tend to be consistently periodic. This basic periodicity, most pronounced in the ECG, caused concern about the compressibility of biodata by available algorithms since all but one of these algorithms were devised especially for telemetry data.

The final report contains a complete description of all the algorithms that are currently being used. For each of the algorithms described, results of a computer simulation of the algorithms applied to an ECG are included, and also results on a similar simulation of selected algorithms applied to the EEG. Prior to the simulation, a thorough evaluation of biomedical status-measure waveforms was made, and they were compared with normal telemetry data parameters. The conclusion drawn from this comparison was that measures such as respiration, body temperature, and blood pressure were sufficiently similar to normal telemetry data, on which simulations had already been performed, to assume that the same degree of compression could be achieved. The exceptions to this were the ECG and the EEG. Both of these parameters were sufficiently different to warrant further inquiry. At this time, it was discovered that data records of these parameters were being prepared for subjection to the computer simulation routines. The results of this other study program were obtained for inclusion in the final report for this study.

Certain conclusions were drawn as a result of the computer simulation; they are: biomedical data can be compressed using standard redundancy-reduction techniques, and compression ratios comparable with normal telemetry data can be achieved(in one case, orders of magnitude greater compression was achieved). Implementation of such techniques is practical and should be used to reduce the bandwidth requirements of biomedical data both for space vehicle telemetry and for point-to-point transmission on the ground.

The standard compression algorithms produced compression ratios as high as 30:1, whereas the technique devised specifically for ECG yielded a compression ratio of 1,800:1. This latter system is more complex than the standard algorithms and requires additional hardware as well as additional memory capacity. For each application of compression to biodata, a tradeoff will have to be made among weight, power, and volume demanded by each algorithm and the reduction in bandwidth achievable.

4.2.2 Analysis of Syntactic Data Compression

Simulation routines provide the only current means of determining the compressibility of biomedical data. In fact, this particular problem is encountered in general application of compression techniques. As part of this study, a brief investigation of this problem was made.

Limitations on computer storage and the high cost of long simulation runs on the computer dictate that the data records being examined be fairly short. Since most data of interest are non-stationary, in a statistical sense, results achieved on short runs are not always indicative of the results that will be achieved during actual mission operation. As a consequence, it is desirable to devise methods of assessing the degree of compressibility and the choice of algorithm directly from specific data characteristics. Another problem area closely associated with those just described is in the determination of the absolute efficiency of currently known algorithms. Continuing studies are being performed with the objectives of evolving more efficient syntactic algorithms, but, as yet, the maximum achievable compression has not been established. Again, it is desirable to examine the maximum average compression ratio that can be achieved as a function of data characteristics and accuracy. This determination will provide an absolute scale on which various compression algorithms can be compared.

The approach taken in this study toward the resolution of these problems was that determination of the maximum average compression ratio would provide insight into a means of deriving compressibility as a function of data characteristics and compression algorithm. Two distinct methods were explored, both of which have their foundations in information theory. The first method postulated that the redundancy removed by a Syntactic data compressor is identically that redundancy which is an integral part of information theory. Then, using the definition of entropy power given by C. E. Shannon and W. Weaver in The Mathematical Theory of Communications, attempts were made to relate the entropy power of a time series with the power spectral density and compressibility. The second method also had the redundancy of information theory as it's starting point, but made use of the average information, and mutual information, concepts of this theory to relate compressibility to data characteristics. Neither of the methods was carried to completion in the sense of a definitive solution.

However, a complete mathematical outline of the approach that must be followed was completed. Both methods appear sufficiently promising to warrant concerted future effort.

Section 5
FUTURE DATA MANAGEMENT

An on-board data system, or, for that matter, any data system, is an integral part of the overall data management system. Its functions include accepting and formatting the data generated by the signal sources; performing computations and logical operations; in many cases providing system control and, when required, operation of on-board displays; finally, it must provide an input to the telemetry transmitter, in proper format, and with appropriate bit rates or bandwidths. Discussion of an on-board data system must include consideration of two major constraints imposed upon such a system, namely, the data sources and the telemetry equipment. These constraints are functions of the data load generated and the capability of the telemetry transmitter.

In the formulation of a data management system for biomedical space missions, the designer is typically confronted with the necessity for making a series of compromises that compress the desirable features of the system into an operable package capable of meeting availability criteria for weight, power, size, reliability, and other conditions. As missions become longer and more complex, it can be expected that the collection and handling of data will become more complex as well. Information demands may well increase in these missions, and the difficulties of transmission will become more of a problem as more and more data are forced into an increasingly constrictive telemetry channel. To properly assess the projected problems of data system design for future biomedical missions, a preliminary evaluation of data volumes or loads anticipated, as well as a determination of telemetry system capabilities, must be made.

First, a set of guidelines is necessary to indicate the types of missions involved. Three major distinctions or classifications of space flight were selected for this study: near-earth orbits, lunar missions, and planetary missions. The near-earth orbit includes missions like those currently being conducted, operational orbiting laboratories, and parking orbits for the departure and return of the other classes of missions. Lunar missions encompass orbital, landing, and missions after a lunar base has been established. Planetary missions have not been categorized beyond a generic classification.

5.1 ANTICIPATED BIODATA VOLUME

The purpose of the biodata sensing system is to provide information on the viable state, safety, and, in future missions, the functional performance capability of the astronauts. This includes both the sensing of significant phenomena and conversion of these phenomena into electrical forms suitable for further manipulation in the data system. Measurement data fall into two general classes:

- Class 1 – Environmental; the external factors affecting and acting upon the life systems
- Class 2 – Psychophysiological responses; the outputs derived from the life systems themselves

Space missions involving human subjects will logically pass through several evolutionary phases with an ultimate objective of establishing man in a functional role as an operator, observer, and a decision-maker, integrated with the other vehicular subsystems. The three major steps in this evolutionary progression and the differentiating objectives are the following:

- Exploratory; determination of unknowns and evaluation of effects of space on life systems
- Developmental; test and evaluation of protective measures
- Operational; status monitoring only

Each of the major classifications of space flight (i.e., near-earth orbit, lunar missions, and planetary missions) will progress through these evolutionary steps. However, the exploratory and developmental phases will generally be shorter for lunar missions than for near-earth orbits, and still shorter for the planetary missions because each succeeding phase is an outgrowth of the preceding work and therefore contains fewer unknowns. Ultimately, operational status will be achieved in all missions, requiring only status monitoring data to be transmitted. In general, these status data will be different for each space flight category in that they will be more inclusive for the more complex mission categories.

Each of the mission categories was thoroughly investigated and data loads elicited for both investigational (exploratory and developmental) and operational of status data. In addition, variations in data load were determined as a function of modifications in mission profile such as duration, crew complement, and extravehicular activities.

The results provided one of the essential inputs for the projection of future data systems and, in addition, were tabulated in the final report for future use.

5.2 TELEMETRY SYSTEM CAPABILITIES

A literature review on telemetry has indicated that two ground station networks will be used for future manned space flights. These are the NASA Manned Spaceflight Network and the Deep Space Instrumentation Facility (DSIF). Literature describing the current capabilities and the development schedule for these facilities was obtained and their contents used extensively in the work described in this section. The NASA Manned Spaceflight Network will be used to monitor all missions out to a slant range of 8,000 nm. Beyond this distance, the functions of command, tracking, telemetry, and data reception will be performed by the DSIF operated by the Jet Propulsion Laboratory.

5.2.1 NASA Manned Spaceflight Network

This network is equipped to receive digital data (PCM), frequency-modulated on a VHF carrier of 235 Mc. The ground stations of this network use Nems-Clarke telemetry receivers which have a noise figure of less than 6 db. The effective noise temperature at the input of the receiver is 870 °K. The ground antenna gain at 235 Mc is typically 30 db. These data and the past experience of the study team in telemetry-system analysis allowed the characteristics of this network to be translated into a set of curves relating the following:

- Signal-to-noise-ratio to probability of bit error for the PCM/FM mode of transmission
- Bit rate range as a function of the probability of bit error
- Bit rate to range as a function of vehicle antenna gain
- Bit rate to range for various vehicle transmitter powers

In addition to these basic relationships, the capabilities of this network to handle television and voice data are presented again as a plot of bandwidth versus range as a function of various parameters. Finally, since this network cannot provide continuous coverage (because of orbit precession and station locations), data on coverage versus orbit inclination have been developed and included in the final report.

5.2.2 DSIF Telemetry System

The deep-space missions will use the DSIF, a network of seven ground stations around the world that provide continuous coverage for such missions. Spacecraft-to-ground communications are accomplished using a 2.3-Gc main carrier. Several data channels may be transmitted on this carrier by using a multiplexing format. The DSIF ground stations will have a 210-ft parabolic antenna with a gain of 53 db and a noiseless cooled maser preamplifier. The effective noise temperature of the receiver is 55° ± 10°K. As was the case for the Manned Spaceflight Network, these data, along with other available information, were used to compile a set of curves that summarize the DSIF capabilities for data, television, and voice communications.

5.3 DATA SYSTEMS

An on-board data system for manned and high-primate space missions fulfills the following purposes in the overall data management system:

- Accepts, formats, and in other ways prepares information for an optimum presentation to the telemetry system
- Permits a maximum amount of information to be accepted from the man as an observer, experimenter, and controller
- Formats the necessary information for on-board displays and for control of the displays
- Adopts itself or other subsystems to changing conditions either automatically, on command by the astronaut(s), or on command from the ground

These objectives must be achieved within the constraints imposed on the overall vehicular data management systems. Some of these constraints have been explored in the previous subsections. In addition to the limitations on bandwidth, other important constraints are those on energy, weight, size, and power consumption of the data system itself. In any given time period only a limited amount of energy can be diverted for any subsystem by the vehicle's energy sources. Since most on-board systems tend to expend power at a constant rate, a time limit may be imposed on operation to remain within the energy constraint. Such an operational constraint may be loosened if the situation demands. An emergency situation would justify diversion of energy by the astronauts from a less vital to a more vital function, such as vehicle-to-earth communications. This diversion would not alter the power/bandwidth constraint; it would only allow a longer term of operation at a given power level (of course, this philosophy could be extended to increase the output power of the transmitter, with a consequent increase in the rate of energy utilization).

The weight, size, and power consumption aspects of on-board systems (actually systems in general) are undergoing rapid and significant improvements with the advent of micro electronics . Because designs using the newer microelectronic techniques can be implemented in so many different ways, it is not possible at this time to establish tradeoffs compatible with the degree of system definition achieved in this study.

of the four purposes stated at the beginning of this section for data systems, the fourth is the one which has the greatest implications for future systems. The first three, although important to total system operation, are for the most part not new in concept, having been necessary to some degree in past systems. In the initial phases of this particular investigational phase of the study, all concepts were interpreted and centered around manned and high-primate missions. However, it soon became apparent that the future operational characteristics being evolved were equally applicable to any future sophisticated space mission. The validity of this statement lies in the realization that man, considered in terms of space missions, becomes just another subsystem. As a subsystem, man is less tolerant of extremes in environmental conditions than other subsystems, therefore requiring considerably more peripheral equipment than the other subsystems. His advantages (the reason for his inclusion) far outweigh these difficulties, however, and derive from his general rational adaptability to situations with little or no a priori information. This report, as well as the final report, concentrates on manned and high-primate missions; but, in light of the preceding discussion, it is clear that the report contents would be equally applicable to any future mission.

A review of initial successes in space, and progress to date, was assessed to determine the directions in which improvements in operation were leading. Two facts became apparent; the experimenters have continuously become more selective in the information they desire from the mission at the expense of raw data and large volumes of data; and the on-board systems become increasingly complex, thereby continually achieving greater autonomy. Extending these trends to future missions has resulted in specific declarations for future data system requirements. The two major declarations of this nature are (1) there exists a need for data compression on three levels; and (2) there exists a need for a diagnostic capability in the systems of the future for both hardware fault assessment, location, and correction, as well as to provide diagnosis of physiological malfunctions that may occur in space environments.

The final phase of this portion of the study was to correlate all the factors discussed in this section and postulate system configurations for future space missions. The systems postulated indicate a progression in complexity with increase in mission complexity from the near-earth-orbit case to the most complex, a planetary mission. The systems are described strictly on a conceptual plane, and no detailed design was attempted.

Section 6
CONCLUSIONS AND RECOMMENDATIONS

This section presents the conclusions and recommendations derived from the present study. First, certain problem areas are identified; following these statements, suggestions and recommendations for alleviating these problems are given.

Specific Conclusions

- A great dearth of quantitative data exists on biological and biomedical equipment. This lack of data creates considerable difficulty and consequent disadvantages in instrument experimental work from the standpoint of both quality and cost.
- Sufficient numbers of basic data acquisition components (sensors, transducers, signal conditioners, etc.) exist for the standard status measures in biomedical work such as ECG, EEG, respiration, and body temperature, although, universally, each component is deficient in some characteristics with respect to the limited "standard" developed during the study.
- The best currently available equipment for instrumenting the basic status measures has been developed for and are (or were) used in NASA programs Little Joe, X-15, Mercury, Gemini, and Apollo.
- The basic acquisition equipment for many of the experimental measures projected for future space missions is unavailable.
- A suitable "standard" consisting of the characteristics and specifications of equipment to be used to measure all required biological measures has not been completely developed.
- All future space missions, including manned and high-primate biomedical missions, will require enhanced data-system capability.

Specific areas that have been isolated during the study are:

(1) Advanced data-compression techniques to provide three distinct levels of compression

(2) Development of a diagnostic capability in the data system for both hardware malfunctions and physiological distress

Recommendations

- To help overcome the current lack of quantitative data on biological and biomedical equipment, it is recommended that contracting agencies recommend or perhaps contractually require that formalized reporting procedures be established to provide equipment descriptions and specifications when the basic contract effort is of a biological or biomedical nature.
- An investigative program should be conducted to elicit all pertinent characteristics, specifications, and quantitative data for equipment necessary to obtain the desired biological or biomedical measures. A resulting "standard" with which all equipment devised for such measures could be compared should be established.
- Initiation and encouragement of an equipment improvement program is recommended. Such a program, which would include improvement of existing equipment, would help ensure that the equipment required for biological or biomedical measures compares with the "standard."
- The many proposed alternative methods of blood pressure measurement should be examined to determine the most effective procedure.
- Development of basic acquisition equipment that is not now available should be investigated.
- Studies should be made to determine methods of achieving capabilities to implement the data system configurations that inevitably will be necessary in future space missions. These studies should emphasize advanced data-compression and diagnostic investigations.

It is incumbent upon the study team to present a detailed program for the resolution of recognized problems in areas in which a cogent and comprehensive program can be laid out. In recognition of this duty, detailed program outlines and descriptions of the work envolved are presented in the final report in the areas of data compression and diagnostics.